University Of Southern Queensland
Faculty of Engineering & Surveying

Stop-Go Mobile Mapping

A dissertation submitted by

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Abstract

The surveying profession has seen many advances in the way that data is captured in the field. Recent years have seen the development of Terrestrial Laser Scanners (TLS) that have offered an alternative to traditional survey techniques. TLS are an automated high speed data capturing device, which can have a reflectance range of upwards of 1000m, making them especially useful for locating terrain in often inaccessible areas.

Within a mine site, TLS have been used for large scale DTM's (pit shells). In these circumstances, surveyors have often put themselves at risk to obtain the best vantage point. Tops of bund, edge of high-walls, edge of low-walls and even pit ramps have been used. For this reason, this dissertation examines a TLS, whilst mounted to a Caterpillar all-terrain loader. This combination (TLS and CAT loader) was designed to enable a safer and more efficient way of capturing data.

To enable all of the field work to be performed within the cabin of the machine, stop-go mobile mapping uses an advanced method of registration. A simple, short backsight location (mounted to the machine) is all that is required in the field.

The registration process requires the use of a Multi-Station Adjustment (MSA) and it is these parameters that are determined from the results of this project. Finally, the accuracies of the data will also be tested and this will determine whether the MSA has worked effectively.

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ENG4111 Research Project Part 1 & ENG4112 Research Project Part 2

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1 Introduction

1.1 *Introduction*

In the surveying industry of today, there is an ever increasing push for businesses to provide fast and accurate data. TLS are instruments with the capabilities of capturing vast amount of spatial data in a very short time.

Although TLS are a very effective way of capturing data, conventional scanning methods have seen surveyors place themselves in a range of vantage positions, so that a large amount of area can be seen from a single position. In the mining industry, tops of bund-walls, edges of high-walls, edges of low-walls or even pit ramps have been used. Many of these locations are quite dangerous, especially in active circuits (roads where large machinery travel as part of everyday mining operations).

Stop-go mobile mapping is one method that can improve the personal safety of surveyors and reduce the field time taken to perform the scanning (Lennon 2009). As all of the work can be performed within the cabin of the machine (explained later in section 2.4), it reduces the interaction between people and machines. Lennon Mine Training states that it is far easier to identify a machine on a mine site than a single person walking around on foot (Lennon 2009). Also, by being inside the cabin of the machine, the surveyor reduces other hazards such as heat exhaustion from the sun. As there is an ever increasing attitude towards safety within a mine (Adams 2009), undertaking survey work that reduces principle hazards, would be the much preferred choice over any other conventional method.

This chapter is designed to summarise the problem, project aim and objectives that will be met, whilst undertaking the project. The concept of stop-go mobile mapping with a Terrestrial Laser Scanner (TLS) will be discussed in great depth for the application of large-scale, terrain modelling, especially for mining purposes. Specific conditions about stop-go mapping, including scan resolutions (intensity and duration) and adjustment parameters for a multi-station adjustment (adjusts the whole data set onto one common plane) will also be considered.

1.2 *Statement of Problem*

Throughout the last couple of years, there has been extensive research and testing on concepts of TLS. Heng Hai, Mark Sinderberry and Adrian Wall just to name a few, all have published documentation of research that deals with TLS. There is however, very limited investigation on stop-go mobile mapping, whilst utilising a TLS.

Stop-go mobile mapping is an even faster method of data capture than the conventional single scan process (a lengthy process that acquires its position from five targets). As a major part of this method is the reduction process (multi-station adjustment), it is essential that additional research be undertaken in this area and ultimately, the accuracy and integrity of the data be tested.

Although stop-go mobile mapping has already been leap-frogged (technology already been overtaken) by continuous TLS. The stop-go concept is more likely to be replicated and trailed by other surveyors as the equipment required is far less expensive and also easier to use. For these reasons, it seems only practical to focus the intensions of the project towards this area, as it is my belief that stop-go mobile mapping is a technology of the future.

1.3 *Project Aim*

To investigate and test for the optimum scan resolutions, adjustment parameters and ultimately the accuracies of stop-go mobile mapping using a Terrestrial Laser Scanner, which incorporates a multi-station adjustment.

1.4 *Project Overview*

1. Scan a large open area that requires several scans by altering the scan resolution and distances between scans for each scan sequence. This will be done with the aid of the CAT 277C, which will be used as a mobile platform for scanning.
2. Perform a multi-station adjustment on the data, using a range of parameters.
3. Create a Digital Terrain Model for each of the adjusted scan sequences.
4. Test the accuracy of each model:
    - To check the positional (horizontal and vertical) integrity of the data, a coordinate value for each reflective target is to be extracted from the mesh of the points. Each set of coordinates from the meshes are to be compared with the original GPS surveyed value. The original GPS values will be considered error free and will therefore be used as a standard of comparison for accuracy assessment.
    - To check the accuracy of the data in a vertical sense (heights), a range of points from chainage 0 right through to chainage 1000 will be compared. This will be achieved by taking GPS measurements in the field, which will later be compared to extrapolated values from the various models.
    - As a broad-scale check, an Isopach surface will be used in conjunction with a cut/fill report between each of the scanned surfaces and that of the traditional scan survey (target registration). This will identify any gross errors with incorrect ‘planes’ positioning associated with the multi-station adjustment.

5. Compare and contrast these results and find the optimum scan resolutions and adjustment parameters. Also, compare the standard deviations and residuals, of the multi-station adjustment for each scan sequence.

1.5 *Summary*

The project background, problem, project aim and objectives have been stated. The broad concept of stop-go mobile mapping using a Terrestrial Laser Scanner (TLS) has also been discussed.

2 Literature Review

2.1 *Introduction*

During the last 10 to 15 years, there have been many advancements in technology throughout the world. This has advanced and modernised many occupations to a great extent, especially in the surveying profession.

This profession has progressed from the ‘old style’ Theodolite and chain, to 1” Total Stations which incorporate EDM’s with reflectorless capabilities (DERM 2009). Furthermore, recent years have seen the development of TLS which are becoming a day-to-day tool of any surveying company.

This literature review explains the concepts of Terrestrial Laser Scanning (TLS), stop-go mapping and the reductions associated with the multi-station adjustment. Also, past research and testing from other dissertations have been analysed to assist with this project.

2.2 *History*

As TLS are a relatively new technology, the history of discovery is only over a few years. Various reports and dissertations have been based on TLS where the accuracies and viability of the instrument have been tested. Mark Sinderberry published a dissertation in 2007 on the accuracies involved with 3D Laser Scanning, whilst utilising different registration methods. Such methods included cloud to cloud registration, target registration and georeferenced registration. The cloud to cloud registration was the only method that was similar to that used in the MSA of this project. Although similar, there were large differences in the reduction methods, therefore it provided an opportunity to still research the MSA, as there was still insufficient research on this topic.

Heng Hai published works in 2008 which involved testing the accuracies of TLS. His findings were conclusive in that TLS were an accurate method of data capture, equal to if not better than conventional methods (total station or GPS) due to the high definition point cloud. Hai also stated that the benefits of TLS are high productivity rates, greater safety to the surveyor and also a reduction in the chance of possible error in the data.

Another publication that is relevant is by Adrian Wall in 2009, where he assessed the viability of a TLS in an open cut mining environment. This is comparable to this project as it deals with large scale DTM's. Wall concludes with various arguments that suggest that the use of a TLS will have numerous benefits, primarily with cost savings, time efficiencies and also an added safety factor. Wall's dissertation has proved the viability of TLS already, however this project endeavours to streamline the process even further (quicker, cheaper, easier and safer).

2.3 *Equipment*

2.3.1 Terrestrial Laser Scanner

A Terrestrial Laser Scanner is a data capturing device that uses either a phase based or time of flight method to measure to different surfaces.

Within the scanner there are several mirrors that assist in data recording. By adjusting certain parameters within the scanner, measurements can be taken at equal angle increments in both the vertical and horizontal plane. This is important for determining the expected resolution at a specified distance. By combining the distance, vertical and horizontal angle, each point can be represented in three dimensions (x, y, z). The results from this are then represented as one massive point cloud, which provides ample data to perform analysis with.

The TLS that will be utilised for this project will be a Riegl Z420i. This scanner's main application is for creating large-scale Digital Terrain Models (DTM's) in both the mining and construction industry.

Some of the manufacturer's specifications are shown below in Table 1, however it should be noted that these values are from average conditions only. The range of the instrument alters considerably, depending on the time of day (Riegl 2001).

Table 1 – TLS Manufacture Specification

Laser Class	Class 1
Measurement Accuracy	Typically ± 0.010m (single shot) Typically ±0.005m (averaged)
Maximum Range	Up to 1000m
Minimum Range	2m
Measurement Rate	Up to 12000 pts/sec
Laser Wavelength	Near infrared
Operating Range	0°C to +40°C

(Riegl 2001)

Figure 1 - Riegl Z420i

(Riegl 2001)

2.3.2 RTK GPS

To fix the location of both the scanner and the backsight, Real Time Kinematic (RTK) GPS will be used: specifically, a Trimble R8 GNSS Receiver (see Figure 2), with an expected accuracy of ±0.025 horizontally and ±0.050 vertically (Trimble 2010). These accuracies can be improved significantly with a clear view of the sky and a good satellite constellation (Trimble 2010).

The R8 is a highly sophisticated machine, as it has the ability to track GPS, GLONASS and Galileo satellites. In conjunction with the R8, a TSC2 will be used as a data storage device and can be seen in Figure 3.

RTK GPS generally acquires its accuracy by initially setting up a base station over a known mark and then sending the corrections to the rover via a radio link. The assumption is made that the rover and base are subject to the same error; therefore it becomes possible to correct the error that the rover is experiencing.

Figure 2 - Trimble R8

Figure 3 – TSC2

2.3.3 CAT Loader

To assist in the stop-go mapping concept, a Caterpillar 277C Multi Terrain Loader will be utilized. This type of machine has been chosen as it provides an ideal scanning platform due to its stability, operator protection and all terrain capabilities. Also, with rubber tracks and a ground pressure of 3.7 psi, the 277C is kind to the environment leaving little or no disturbance.

Figure 4 – Caterpillar 277C

The main manufacturer's specifications are listed in Table 2, however it should be noted that these values are from average conditions only.

Table 2 – Caterpillar Manufacture Specification

Safety Equipment	ROPS, FOPS and Fire Suppression Unit
Engine Size	84 hp
Raised Bucket Height	4.0 m
Weight	4307 kg
Ground Impact	3.7 psi

(Caterpillar 2008)

2.4 *Terrestrial Laser Scanner*

2.4.1 Reflectorless

Dramatic advances in technology have seen the development of direct reflex (DR) in total stations. Reflectorless as it is otherwise known, does not require a prism to get a reflection. Simply, measurements can be taken directly from different surfaces quickly and remotely. This is very helpful, especially in situations where the target is in a dangerous or inaccessible position. Examples of where reflectorless would be used are:

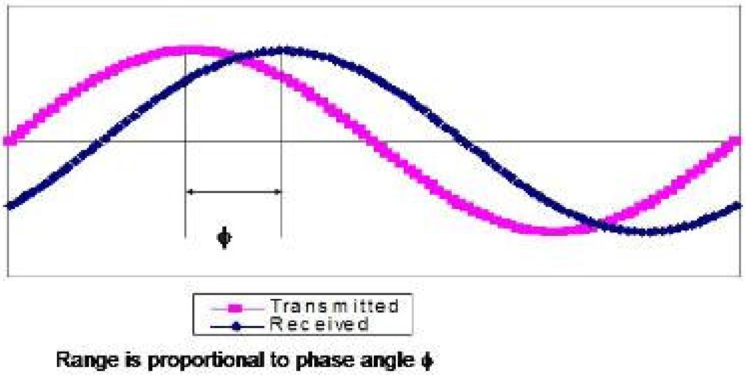
- Road surveys where closing the road is not an option
- Tunnel profiling
- Building/structural monitoring

The concept of reflectorless technology is the underlying principle of how Terrestrial Laser Scanners work. Direct reflex is made possible by either time of flight or phase based solutions.

2.4.2 Phase Based

Similar to modern day total stations, a phased based scanner uses a modulated carrier wave (sine wave) to measure between objects (GIA 2006). The scanner emits the signal towards the target and then it is reflected back to the scanner. This enables a comparison between the transmitted wave and the received wave (known as the phase shift – Φ). The phase shift (partial cycle) is added to the full number of sine wave cycles to determine the total distance (sine wave is known distance). Figure 5 illustrates the phase shift, within the sine wave cycle.

Figure 5 – Phase Shift



(GIA 2006)

Phase based scanners are believed to have a greater accuracy as opposed to time of flight scanners due to the shortness of the sine wave. This however limits the range that the scanner can measure, which sometimes renders the instrument inadequate in different situations.

2.4.3 Pulsed Time of Flight (TOF)

Pulsed time of flight scanners are widely used throughout the mining workplace, unlike phase based scanners. This is mainly due to the ability to measure longer distances. TOF scanners work by emitting their own energy source. A brief light pulse is aimed at the target and the time in which the signal takes to return is recorded Lichti (2002). The distance the surface is from the scanner can be calculated from the following equation:

$$d = \frac{(c \times t)}{2}$$

Where:

d	=	distance
c	=	speed of light (in a controlled environment)
t	=	time the signal took to return to the scanner

Although the speed of light is calculated within a controlled environment and can alter significantly when compared to the real world, the error associated with this problem is insignificant, due to the latest sensor and adjustment technology.

2.5 *Stop-Go Mobile Mapping Theory*

The stop-go mobile mapping theory is quite simple in concept. As its name suggests, the scanner is attached to the vehicle, so that it can easily be moved from one position to another. In this case, an all terrain loader was used and the scanner and backsight attached to the front (shown in Figure 6 and 7).

Figure 6 – Scanner and Loader combination

Figure 7 - Scanner and Loader combination

For each scan to be completed, the machine must be immobile. During this time, the scanner is raised into the air for a high vantage point and the locations of both the scanner and backsight recorded by the RTK GPS. Once finished scanning and recording at one location, the machine is then driven to the next position, where the scanning process will be repeated until the entire area has been surveyed.

2.6 *Registration*

Scanning registration is an integral part of the process. Its purpose is to join all of the scans together, to become a single entity. To enable the multi-station adjustment to work, a minimum of two scans are required (three preferably), with a minimum of 30% overlap.

The software used to run the scanner is Riscan Pro. In this program, numerous variables and characteristics can be set to obtain different outcomes. After field scanning has been completed, each of the scans has to be registered. The process is as follows:

- Import coordinates into the TPL (Tie Point List) GLCS (Global Coordinate System).
- Expand the first scan, right click on SOP and select Backsight Orientation option
- Enter the corresponding coordinates for both the scanner and backsights position
- Perform a truncation on the scan, as coordinate values greater than 2,000,000 don't allow the software to work effectively (the truncation is later reversed, after the multi-station adjustment has been performed)
- Repeat the process for every scan

Once all of the scans have been registered, the data is now ready to be multi-station adjusted (MSA). This will ensure that we have no tilted sets of scan data.

- The first step is to create 'poly-data' for overlapping areas (to make sure that we have sufficient common data to fit the scan clouds together)
- Start the adjustment
  - Have to 'lock' the scanners position and leave the backsight 'free'
  - Analyse the data first with a search radius of approximately 15meters (this will find common plains as the scans are already roughly aligned)
  - Halve the search radius and check what the standard deviation is. If not deemed acceptable, repeat the process until a reasonable value is calculated.
  - Once acceptable, press compute and the adjustment is complete. The dialog box will provide a range of information about the statistics of the adjustment, including a histogram graph, standard deviations and a 3-D orbital ball.

Once completed, the scans are exported from Riscan Pro, into Cyclone, where manipulation and analysis of the data can be performed. Appendix 1 is a detailed breakdown of the registration and multi-station adjustment process.

2.7 *Accuracy*

Laser scanning accuracy can be described in many ways, including range accuracy, angular accuracy, spot size or even resolution (intensity) (Schulz 2004). Essentially, the difference between the 3D model and the true surface at the same point is a practical way of determining the accuracy of a scan.

Although the Riegl Z420i has a standalone accuracy of ±0.010m, the combination of other variables may considerably compromise this accuracy. As the locations of both the Scanner and the Backsight are coordinated by means of RTK GPS, it has an expected accuracy of ±0.025m (if not worse).

GPS is used to orientate each of the scans by the simple back-sight method (target no more than three meters away). Immediately, surveyors would disregard this as not an option, as it is widely known that the distance of the backsight has direct impact on the accuracy of each measurement (Chris 2007). However, only a 'rough' orientation is all that is required for the multi-station adjustment to work adequately.

When the adjustment is run, the software finds common planes within each of the scans. It then holds the scanners position as fixed and then adjusts the location of the backsight, to fit the newly found common planes. The standard deviation of the adjustment results is calculated and it is anticipated to be approximately ±0.030m (slightly worse than GPS accuracy). As the purpose of this project is to find optimum parameters for the multi-station adjustment for large scale DTM's, this accuracy is deemed acceptable.

It should be noted however, that at least 30% overlap is required and that more than two scans is highly desirable to undertake a multi-station adjustment.

2.8 *Summary*

This chapter has provided details about the specific equipment that will be used for the project, including the Terrestrial Laser Scanner, RTK GPS and the CAT Loader. It has also explained key concepts associated with stop-go mapping and the reductions associated with the multi-station adjustment.

3 Methodology

3.1 *Introduction*

There is very limited investigation into stop-go mobile mapping. For this reason, the purpose of this chapter is to provide the reader with a better understanding of both the field and office procedures that are associated with this project.

Therefore, it only seems logical to outline specific details on the test design (scan resolutions, adjustment parameters and associated accuracies). Also, as a major part of this method is the reduction process (multi-station adjustment), it is essential that additional explanation of this task be undertaken.

3.2 *Test Design*

A test area of approximately 1km long will be used, so that several scans are required to cover the whole area. To determine the optimum scan resolutions, we must scan the area according to the following parameters shown in Table 3.

Table 3 - Series A (approx. 100m apart)

Scan Time	Scan Resolution (100.0m)
1' 30"	0.350
3' 00"	0.250
4' 30"	0.200
6' 00"	0.175
7' 30"	0.155

In total, there were 5 scan sequences ranging from a single scan time of 1’ 30” through to 7’ 30”.

All of the above scan sequences will be completed with the scanner and loader combination. An additional scan succession involving the traditional scanning method will also have to be undertaken as a standard comparison. This will involve the scanner being stabilised on a tripod, a 10' 37" scan of the surrounds and also fine scanning each of the 5 targets. This method is registered by the target recognition process and will form the base surface for the cut/fill comparison. The target recognition process is a tried and tested procedure that has been used for laser scanning surveys throughout the past few years (Hoffman 2005).

3.3 *Data Acquisition*

Each of the test scans will be situated according to the prescribed distances in the test design specifications. Once the loader and scanner are in position, the scanner will be lifted into the air using the hydraulic lift system of the machine, to obtain a clear view of the surroundings. To prevent movement in the lift arms, the hydraulic system has been fitted with 'lock-out' valves that prohibit oil flow. Also, as the machine is quite heavy, movement from prevailing winds is insignificant. Once in the air, the scanner will be set (desired resolution) and scanning will commence. To utilise time efficiently, the positions of the scanner and the backsight target will be recorded from within the cab (Bluetooth both antennas). Once the scan is complete, we simply progress to the next position and recommence the procedure until the whole area has been surveyed.

All of the scan data will be recorded electronically in Riscan Pro, where it will be further analysed once back in the office. Similarly, the coordinate values for the scanner and backsight target will be recorded in the TSC2 (data recorded) where they can easily be downloaded at a further date.

3.4 *Survey Control*

As the project is coordinated through the means of RTK GPS, there is not a lot of survey control necessary for the job. At least two stations will have to be surveyed however, which include:

- Station 1 - Permanent control for the use of a base station near one end of the job. A navigated solution for the position will be sufficient with the coordinate system being set to MGA, Zone 55.
- Station 2 - Permanent control at the opposite end to the base station, so that a check-shot can be taken (for QA purposes).
- Additional Marks - For additional survey purposes. Also as recovery marks, should primary control be lost/destroyed.

3.5 *Office Procedures*

Once all of the data has been captured in the field, it can be brought back and downloaded onto the office computers. The first procedure is to register the data (see section 2.5) with the appropriate coordinates. Once registered, the MSA can be performed. A range of parameters will be used for all the scans, so that optimum constraints can be determined.

Each scan sequence is exported from Riscan, into Cyclone, where the scans are unified, cleaned and meshed. From here, specific points can be extrapolated such as surface levels or even control points (targets). Also, cut/fill volume calculations can also be executed.

3.6 *Analysis*

Before the scans are to be performed, several uniquely identifiable points (reflective targets) are to be placed throughout the work area, so that comparisons can be done.

To test the accuracy of the multi-station adjustment, various evaluations are to be made. Three methods of assessment have been developed and are as follows:

<u>Method 1</u>

To check the positional (horizontal and vertical) integrity of the data, a coordinate value for each reflective target is to be extracted from the mesh. Each set of coordinates from the mesh's are to be compared with the original GPS surveyed value.

<u>Method 2</u>

To check the verticality of the data, a range of points from chainage 0 right through to chainage 1000 will be compared. This will be done by GPS measurements in the field, which will later be compared to extrapolated values from the various models.

<u>Method 3</u>

As a broad-scale check, a cut/fill comparison between each of the scanned surfaces and that of the traditional scan survey (target registration) will also be undertaken. This will identify any gross errors with incorrect 'planes' positioning associated with the multi-station adjustment.

3.7 *Summary*

In this chapter, we have discussed the field and office work that is associated with the project. Such details included data acquisition, office procedures and various other tasks. We have also discussed how we intend to analyse the data, in terms of both horizontal and vertical accuracy.

4 Results & Analysis

4.1 *Base Surface*

4.1.1 Target Comparison

To verify the accuracy of the base surface survey, each of the reflective targets were fine scanned so that their individual positions could be compared to the true values. Appendix 6.1 shows the measured results of the scanned positions.

Figures 8, 9 and 10 are a comparison between the scanned target positions and that of the true (GPS measured) positions. It is evident that there are no values greater than ± 0.041m, which would be deemed acceptable for a large scale DTM. Generally, the results indicate that most residuals are approximately ± 0.020m, which is what you would expect to achieve from GPS measurements. Therefore, it would be appropriate to use this surface for our base comparison. Appendix 6.7 shows the tabulated results for this comparison.

Figure 8 – Easting Results

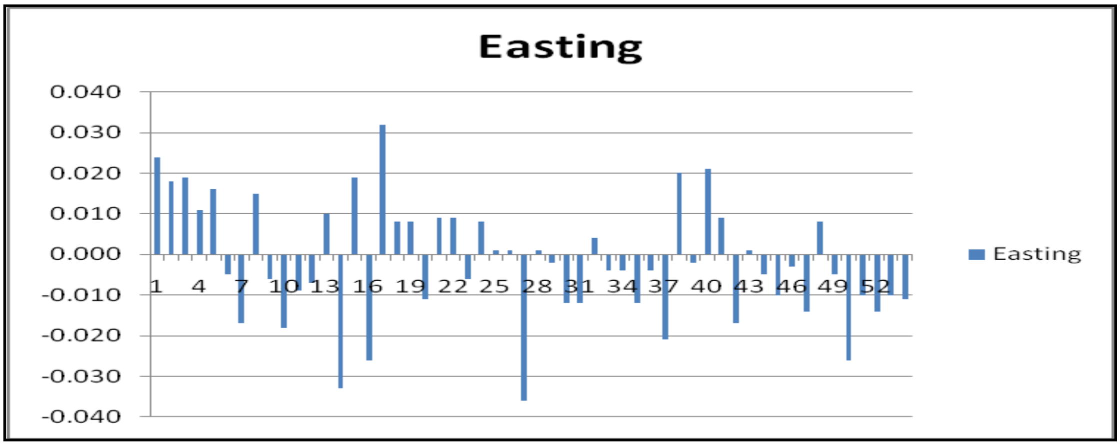


Figure 9 – Northing Results

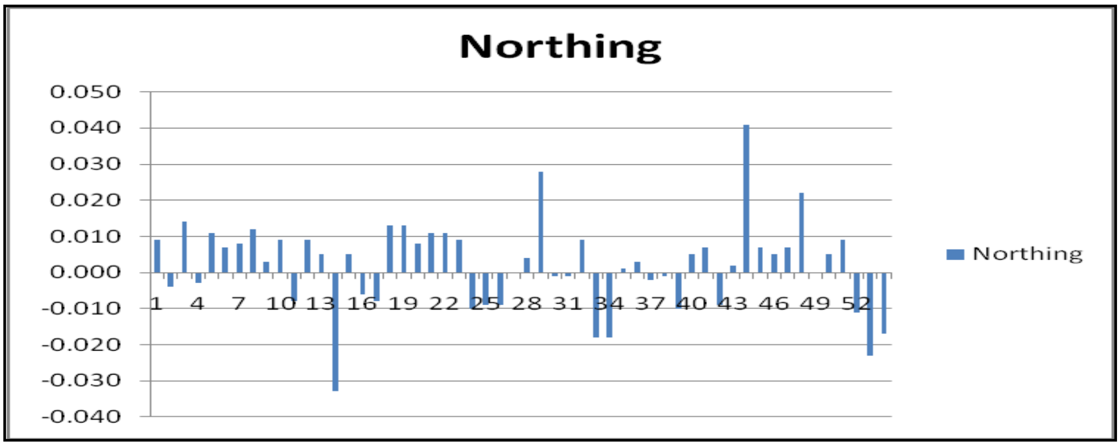
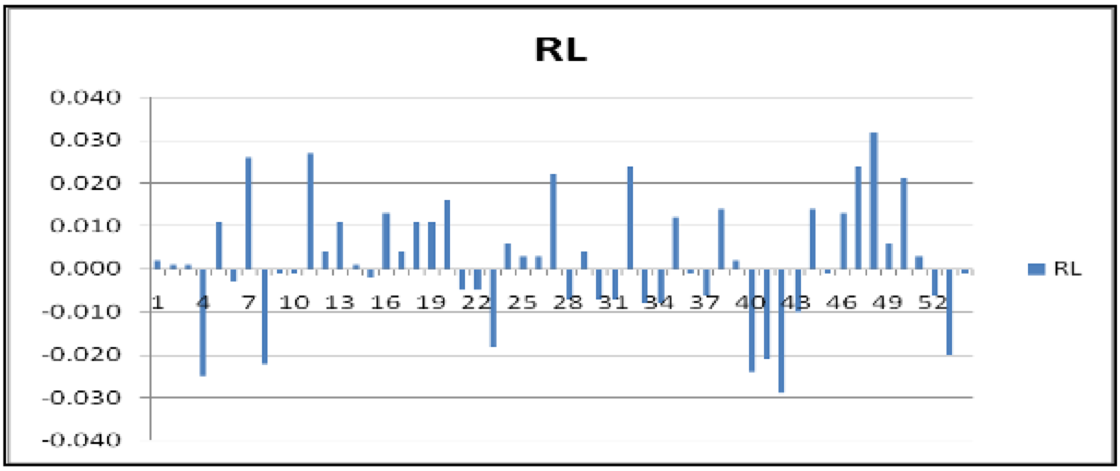


Figure 10 – RL Results

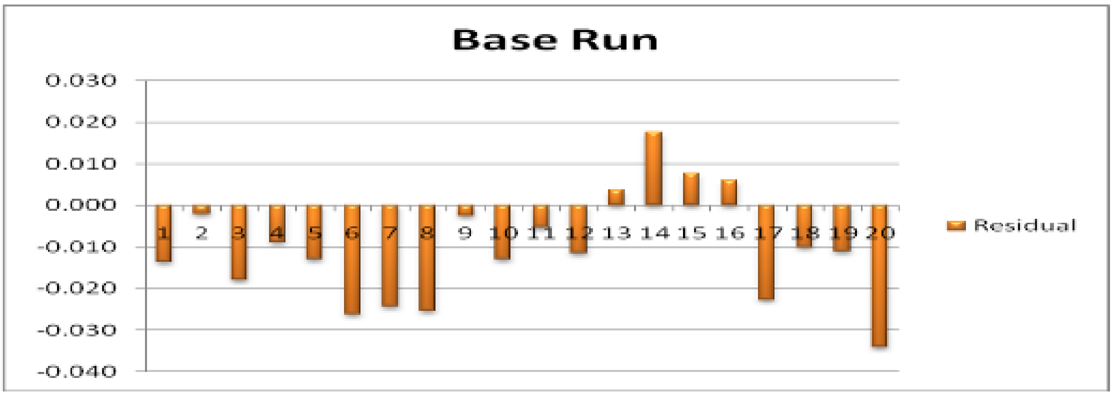


4.1.2 Surface Level

As the vertical heights proved to be the worst accurate, additional checks had to be done to confirm accuracy. Twenty measurements were taken by the GPS that extended from chainage 0 right through to chainage 1000. These measurements were then compared to each of the models.

The residuals of the comparison of RL (height) between the GPS measurements and that of the extrapolated values from the mesh are shown in Figure 11. From this, it is clear that the worst difference is -0.034. Further analysis reveals that the mean is only ± 0.0139. This confirms the base surface model as accurate and therefore appropriate to use as a standard of comparison. Appendix 6.8 shows the tabulated results for this comparison.

Figure 11 – Comparison between GPS measurements and Base Run



4.2 *100m Scan Position*

4.2.1 Target Comparison

The measured results for the target comparisons are shown in the following Appendices:

- 1’ 30” scan are shown in Appendix 7.2
- 3’ 00” scan are shown in Appendix 7.3
- 4’ 30” scan are shown in Appendix 7.4
- 6’ 00” scan are shown in Appendix 7.5
- 7’ 30” scan are shown in Appendix 7.6

To identify what the positional accuracies are of each of the scan sequences, a simple comparison between the scanned target positions and that of the true (GPS measured) positions was undertaken. Any values that were ± 0.100m are flagged in red, as this would be the acceptable tolerance for a large scale DTM (especially for mining applications). Although this seems quite large, you have to remember that laser scanning a surface will result in a high-definition model, far more accurate than convention methods, where previously, surveyors would average out the terrain anyway.

The results for the 1’ 30” scan indicate that the adjustment has been successful for horizontal positional accuracies, but has failed for verticality. Several measurements exceed the tolerance of ± 0.100m for height (RL). This can be seen in Appendix 6.10.

The results for the 3’ 00” scan indicate that the adjustment has also been successful for horizontal positional accuracies, but again, failed for verticality. Although several measurements exceed the tolerance of ± 0.100m for height (RL), the total number of measurements in error has decreased. This can be seen in Appendix 6.11.

The results for the 4’ 30” scan indicate that the adjustment has also been nearly successful for both horizontal and vertical positions. Only one vertical value exceeds the tolerance of ± 0.100m and can be seen in table 6. The error ratio for this scan is 2.4:100, which is quite low. Also, as the value is only 0.007 out of tolerance, it could be argued that this scan resolution (time) would be acceptable for most applications.

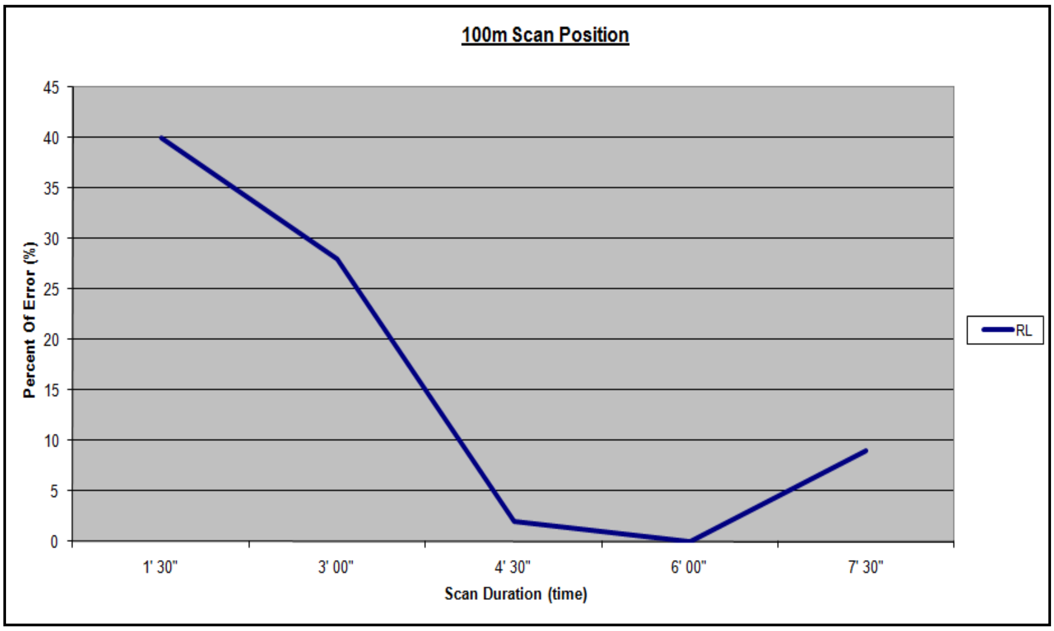
The results for the 6’ 00” scan indicate that the adjustment has fully been successful for both horizontal and vertical positions. No values exceed the tolerance of ± 0.100m (refer Appendix 6.13). Generally, horizontal position is approximately ±0.025m and vertical ±0.048m. Based on this analysis, this scan time would be suitable to use for other DTM.

The results for the 7’ 30” scan indicate that the adjustment has been successful for horizontal accuracy, but has been exceeded for verticality. Four measurements lie outside the tolerance of ± 0.100m (refer Appendix 6.14). This was not expected, as there was a trend before that signifies that the longer the scan, the better the results that were obtained.

One plausible reason why this occurred was that, as the scan duration was longer, it obviously picked up more data. This would be a problem as on either side of the subject area there were two paddocks of irrigated crop. As the scanner measures data in a 360° manner, a large portion of the crop would have been included in the multi-station adjustment. This would be undesirable, as the plants would be highly susceptible to movement from natural forces such as wind.

Figure 12 shows the relationship between scan duration and vertical accuracy. A trend occurs that signifies that the longer the scan duration, the greater the improvement for RL, until a time of 7' 30". From the graph, a 6' 00" scan time would suggest optimum scan duration.

Figure 12 – Scan Duration V's Vertical Accuracy



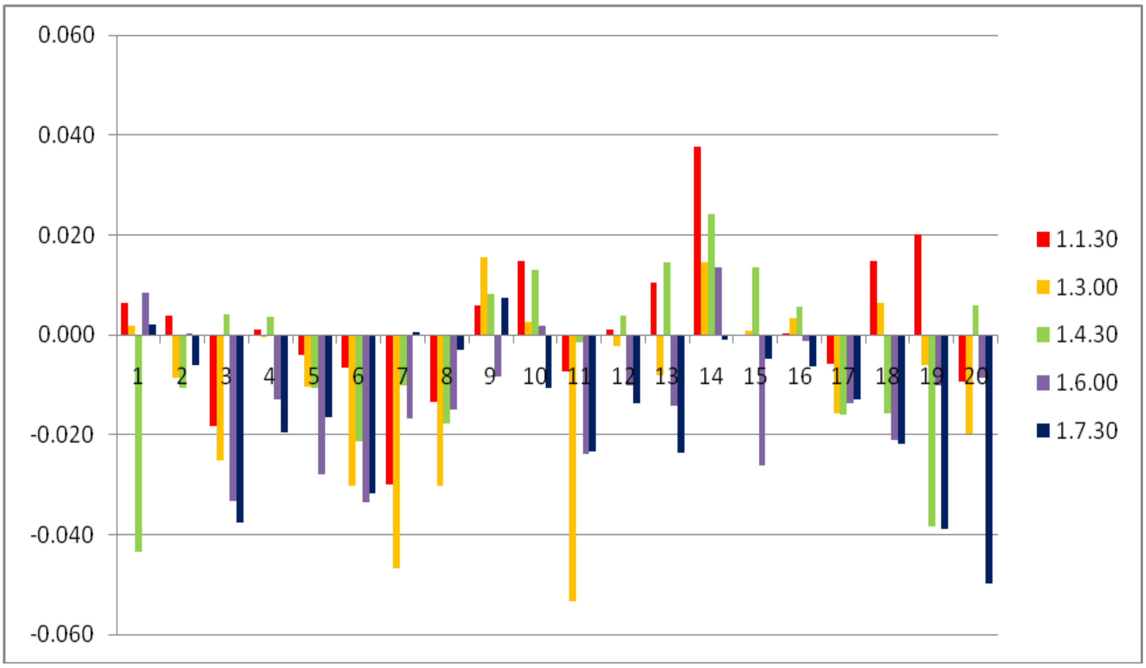
4.2.2 *Surface Level*

As the target results showed that the vertical accuracy was generally the worst, additional checks were undertaken. Twenty measurements were taken with the RTK GPS that extended from chainage 0m right through to chainage 1000m. All the measurements were compared to each of the models, including the base surface to test and verify the accuracy of the data.

Figure 13 shows the results for each surface, as compared to the original GPS observations. All the residuals except for one value from within the 3’ 00” scan were below ± 0.050m. This presents slightly different results to that of the target comparisons, where several of the quicker scans yielded poor results.

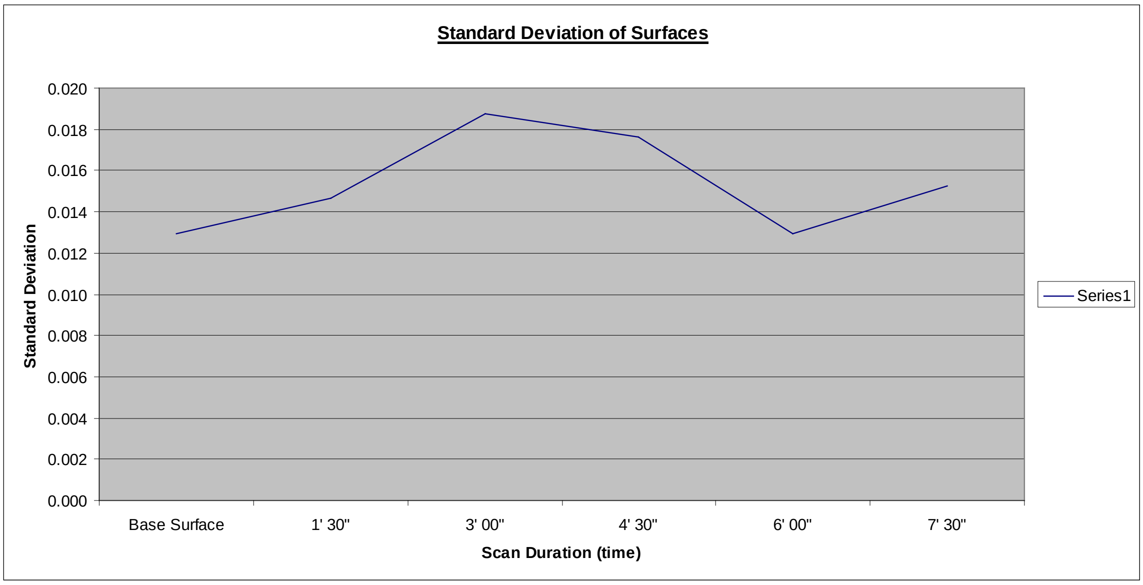
Although four out of the five scan durations gave adequate results, consideration still has to be given to the target comparisons. With the combination of these results, a 6’ 00” scan time would seem desirable. Appendix 6.9 shows the tabulated results for this comparison.

Figure 13 - Comparison between GPS measurements and Scan Durations



The standard deviation was also calculated for each scan surface. A graph of these values is shown in Figure 14.

Figure 14 – Standard Deviation of Surfaces



These results suggest similar accuracies to the target comparisons. The 1' 30" scan is the only exception, where the standard deviation is actually better than the 3'00" and 4' 30" scans. A similar trend occurs that shows that the standard deviation increases with scan duration until a time of 6' 00". The 7' 30" has a worse standard deviation than the 6' 00", which supports the assumption that the MSA has used too much of unstable crop data in the adjustment.

It should be noted however, that the standard deviation of the 6' 00" scan is the same as the base surface standard deviation of 0.013m. This further strengthens the argument that a 6' 00" would be optimal for data capture.

4.2.3 DTM

A cut/fill comparison between the base surface and each of the scan durations was undertaken. The results obtained were very interesting and further supported the use of stop-go mobile mapping.

The following are the results for the base surface and the 1’ 30” surface scan comparison:

Cut volume: 752.27 C.M.
Fill volume: 169.13 C.M.

Area in Cut: 12,590.06 S.M.
Area in Fill: 5,114.74 S.M.
Area exactly in daylight: 515.59 S.M.
Total inclusion area: 18,220.39 S.M.

Average cut depth: 0.06 meters
Average fill depth: 0.03 meters

It is important to highlight the significance of the average cut and fill depth. The average cut depth is 0.060m and the fill depth of 0.030m. These results are undesirable as there is a wide degree of error with a range of 0.090m.

The following are the results for the base surface and the 3’ 00” surface scan comparison:

Cut volume: 450.06 C.M.
Fill volume: 156.11 C.M.

Area in Cut: 11,329.80 S.M.
Area in Fill: 6,093.02 S.M.
Area exactly in daylight: 797.48 S.M.
Total inclusion area: 18,220.30 S.M.

Average cut depth: 0.04 meters
Average fill depth: 0.03 meters

The average cut depth is 0.040m and the fill depth of 0.030m. These results have improved from the 1’ 30” scan surface, but still are impractical for use.

The following are the results for the base surface and the 4’ 30” surface scan comparison:

Cut volume: 217.77 C.M.
Fill volume: 140.78 C.M.

Area in Cut: 9,612.16 S.M.
Area in Fill: 6,911.68 S.M.
Area exactly in daylight: 1,695.39 S.M.
Total inclusion area: 18,219.23 S.M.

Average cut depth: 0.02 meters
Average fill depth: 0.02 meters

The average cut depth is 0.020m and the fill depth of 0.020m. These results are better than both the 1’ 30” and 3’ 00” scans. There is only an average range of 0.040m, which indicates good results.

The results for the base surface and the 6’ 00” scan surface are as follows:

Cut volume: 187.91 C.M.
Fill volume: 138.69 C.M.

Area in Cut: 8,380.81 S.M.
Area in Fill: 7,688.57 S.M.
Area exactly in daylight: 2,151.05 S.M.
Total inclusion area: 18,220.43 S.M.

Average cut depth: 0.02 meters
Average fill depth: 0.02 meters

The average cut depth is 0.020m and the fill depth of 0.020m. These results are equal to the 4’ 00” scans. Further analysis of the results reveal that the 6’ 00” scan has a higher ‘daylight’ area than the 4’ 00” scan. This refers to the area of the surface that is neither cut nor fill (merely the same as the base surface).

The following are the results for the base surface and the 7’ 30” surface scan comparison:

Cut volume: 173.99 C.M.
Fill volume: 209.27 C.M.

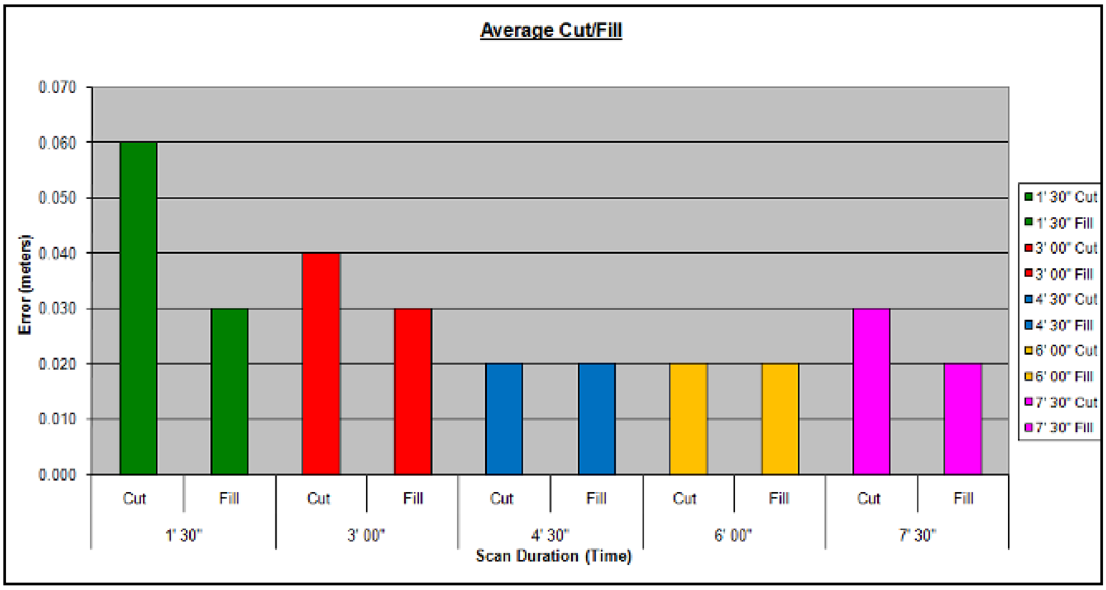
Area in Cut: 6,684.87 S.M.
Area in Fill: 9,833.14 S.M.
Area exactly in daylight: 1,702.40 S.M.
Total inclusion area: 18,220.41 S.M.

Average cut depth: 0.03 meters
Average fill depth: 0.02 meters

As expected, the results from the 7’ 30” scan are slightly worse than the 6’ 00” scan. The average cut depth is 0.030m and the fill depth of 0.020m.

Figure 15 shows a graph of the average cut/fill depths for each scan, when compared to the base surface. A trend once again occurs which indicates that by increasing the scan duration, it also increases the accuracy of the data, until a time of 7' 30", where vertical accuracy is decreased. It is interesting to note however, that the 4' 30" scan has the same results as the 6' 00" scan.

Figure 15 – Average Cut/Fill Depths



Figures 16 and 17 show screen dumps from the software package Cyclone, which was used in the comparison of each of the models. Figure 16 is from a 6' 00" scan duration and mirrors the accuracies obtained. The Base Surface (grey) was overlayed with the 6' 00" scan (blue) for a visual inspection of the data. As the whole area is a mixture of blue and grey (speckled) and is distributed evenly across the whole surface, it indicates that the MSA has worked effectively.

Figure 16 – 6’ 00” Scan Duration

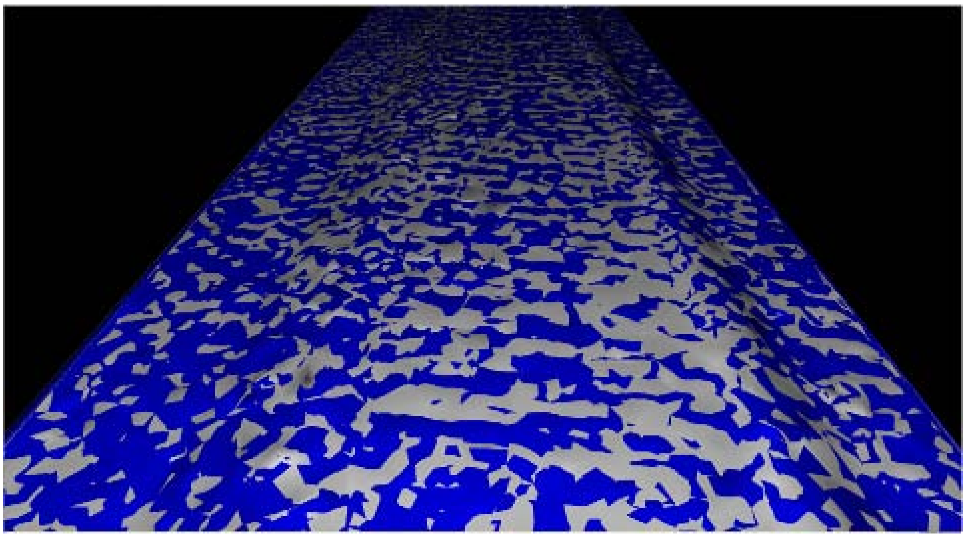
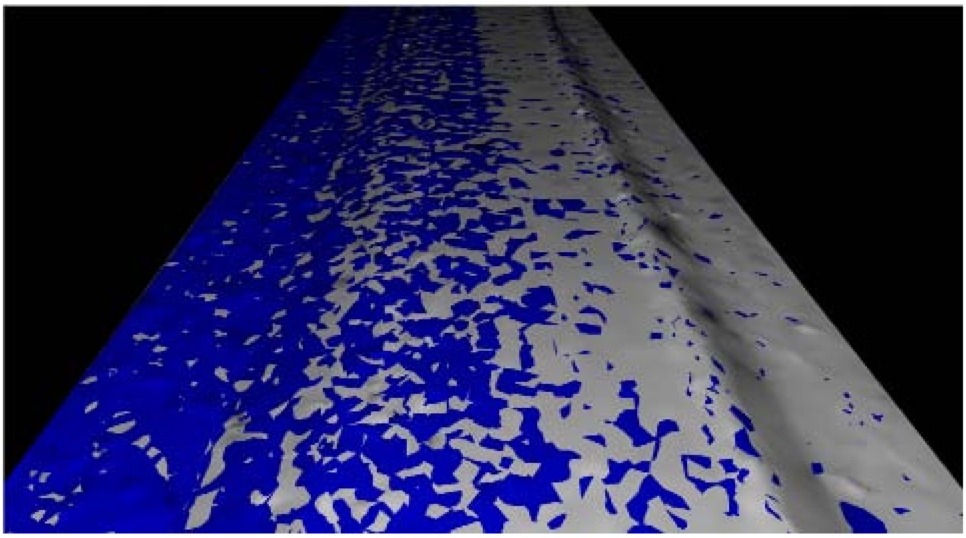


Figure 17 however is from a 1’30” scan (blue) and base surface (grey) comparison. As blue and grey is not distributed evenly, rather tends to favour a particular side, it signifies that the MSA has failed from a lack of data. The distinct line separating each surface in the middle results from the 1’ 30” scan being tilted incorrectly left and right. This is directly linked to the lack of data used in the MSA, caused from the unstable crop on either side of the ditch.

Figure 17 - 4’ 30” Scan Duration

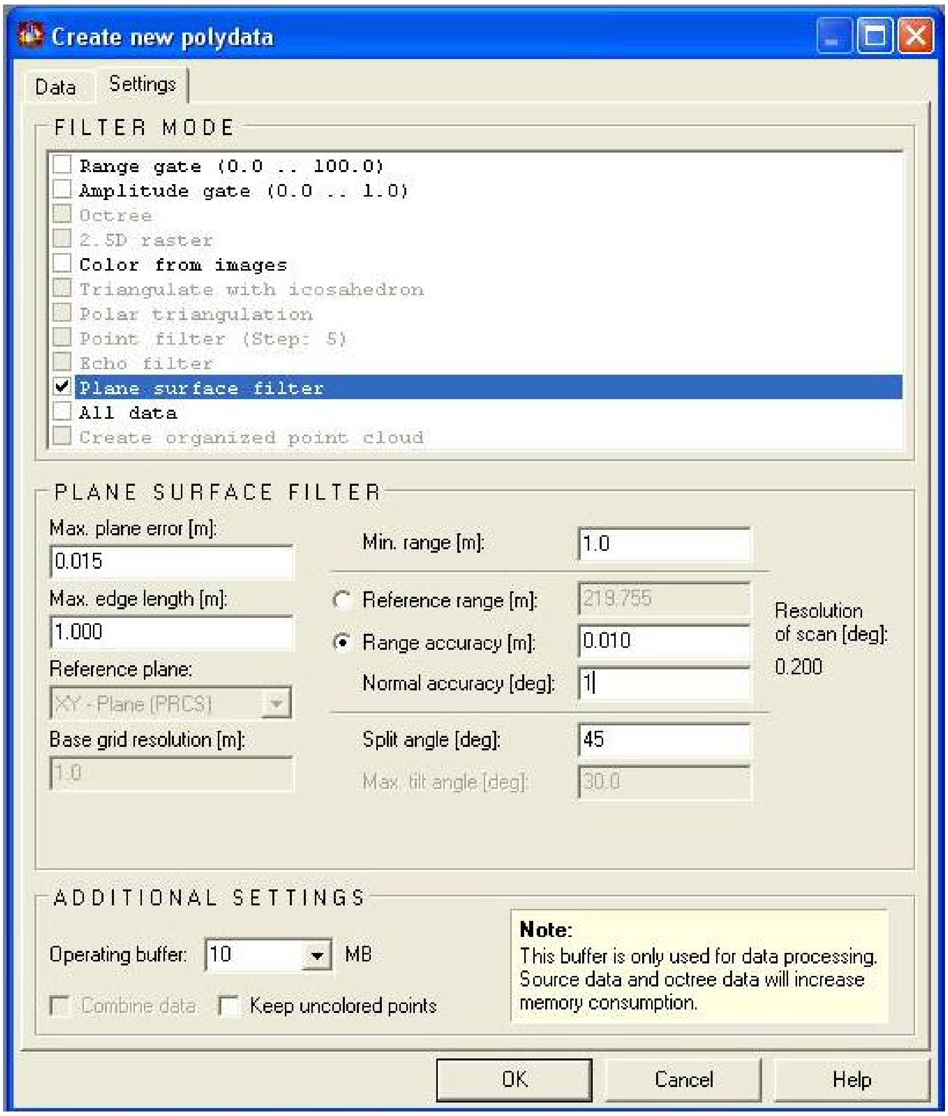


4.3 *MSA Results*

4.3.1 Prepare Data

To perform the multi-station adjustment, we must first prepare the data. In this task, a series of 'polydata' is created for each scan, which essentially identifies where all the common overlap is present. Through various testing and from the assistance from C.R. Kennedy (software providers), appropriate parameters of all the input variables has been derived. This can be seen in Figure 18.

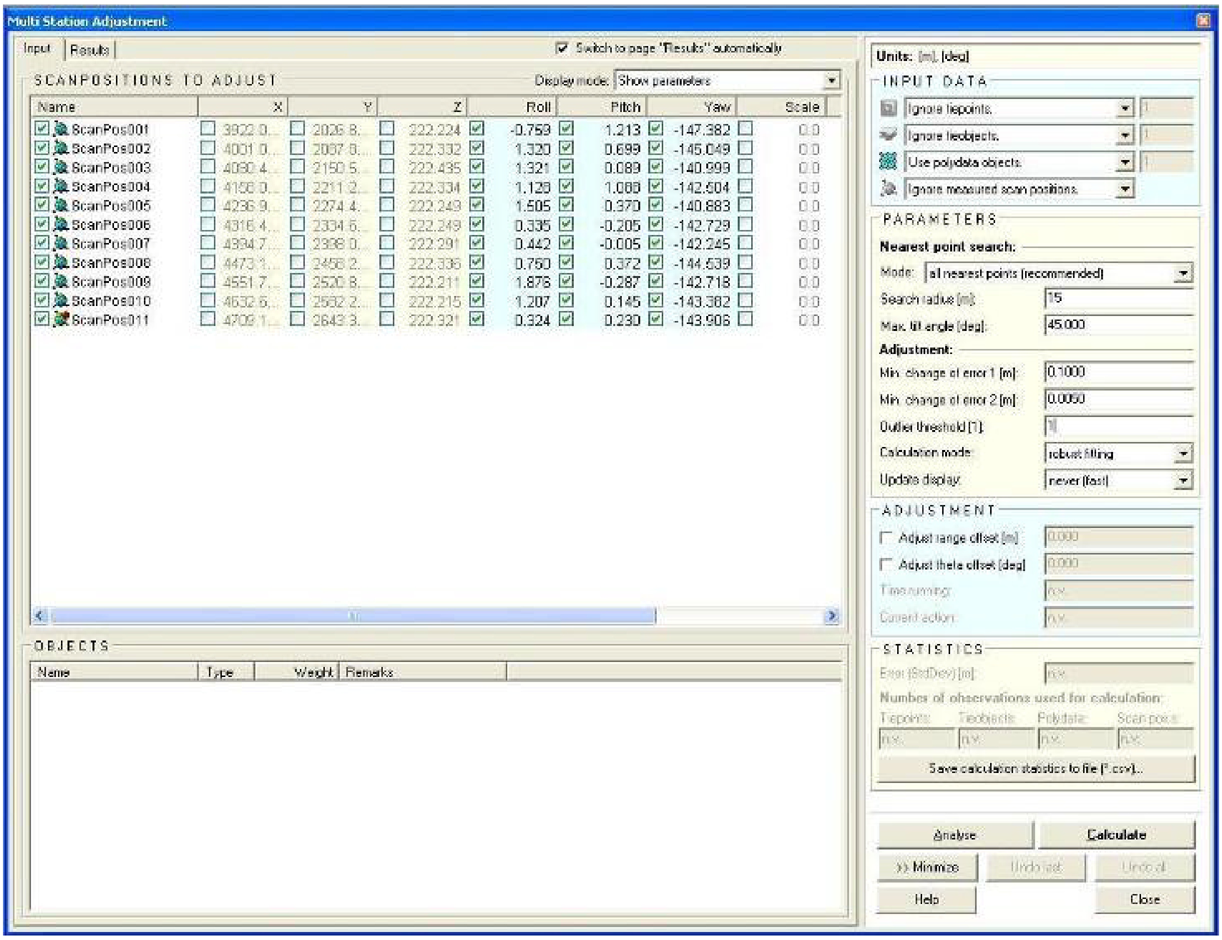
Figure 18 – Parameters for the preparation of the MSA



4.3.2 MSA Adjustment

Similar to the values involved with the preparation of the data, the adjustment parameters for the MSA have been once again derived from various testing and from the assistance from C.R. Kennedy. Figure 19 shows the parameters that are to be used for the initial adjustment. This initial adjustment involves the analysis of the data. Once this has been completed, the search radius must be tightened (15m changed to 1m), then the MSA can be calculated and the adjustment completed.

Figure 19 - Parameters for the MSA



5 Conclusion & Recommendations

5.1 *Conclusion*

The data gained from fine scanning each target gave some interesting results in regards to positional accuracy. A trend occurred that signified the longer the scan, the better the results that were obtained, as more over-lap was present for the MSA. This however was not held true with the 7’ 00” scan, where vertical accuracy was decreased.

The comparison of the surface levels signified that only the 3’ 00” scan failed the test. It should be noted that both the 4’ 30” and 6’ 00” scans both passed easily. Finally, the surface comparisons illustrated that the 4’ 30” and 6’ 00” scans yielded the highest accuracies.

As the 6’ 00” scan had no errors present in any of the tests, it would suggest that this scan resolution would be effective in producing a large-scale DTM. A slightly quicker time such as 5’ 00” may also prove adequate, as the 4’ 30 scan time also had high results. This would seem more practical, as ultimately it would minimise field time.

The adjustment parameters have also been concluded for both the preparation of the data and the actual MSA as well. These parameters can alter the data significantly depending on the desired input/output of the data. Therefore it is important to make sure the correct values are entered into the MSA. These variables can be seen in section 4.3 (MSA Results).

Although the test area was only a narrow strip (approx. 40m wide x 1000m long), satisfactory results were still achieved. This can only imply that by having a wider area to scan, would improve the results further, as more over-lap would be present for the MSA. The actual accuracies expected to be achieved from a 6’ 00” scan would be ±0.100m for positional data (tiepoints). Scan surface models (DTM) would have an average cut/fill depth of ±0.020m away from the mean.

5.2 *Recommendations*

The project was limited only to the area in which the testing occurred. Although the test area was not ideal, it did provide a worst case scenario. Further research should be performed in an area which is wider, so that the MSA can use a full 360° view. Furthermore, the inclusion of near-vertical faces such as stockpiles may assist in increasing the accuracy of the heights.

6 Appendices

6.1 *Appendix Base Surface Scanned Targets*

Base Surface - Scanned Targets					
Target Name	Easting	Northing	RL	Target Size	Target Distance
TGT01	633955.428	7402063.498	217.981	0.114	51.773
TGT01	633955.434	7402063.511	217.982	0.114	50.337
TGT02	633967.593	7402050.857	218.900	0.112	52.737
TGT02	633967.601	7402050.874	218.926	0.112	48.506
TGT03	634033.846	7402125.120	218.085	0.114	52.538
TGT03	634033.867	7402125.124	218.099	0.121	150.723
TGT03	634033.879	7402125.123	218.070	0.116	51.081
TGT04	634046.087	7402111.687	218.948	0.114	50.213
TGT04	634046.108	7402111.696	218.927	0.148	151.819
TGT04	634046.120	7402111.690	218.927	0.113	52.415
TGT05	634112.214	7402186.707	218.192	0.113	50.012
TGT06	634124.310	7402172.613	218.823	0.115	49.809
TGT07	634191.116	7402248.793	218.184	0.111	51.301
TGT07	634191.159	7402248.831	218.194	0.098	350.603
TGT08	634203.766	7402235.047	218.924	0.111	49.009
TGT08	634203.811	7402235.058	218.909	0.142	150.589
TGT09	634272.165	7402312.600	218.291	0.130	148.923
TGT09	634272.189	7402312.579	218.284	0.114	48.199
TGT09	634272.189	7402312.579	218.284	0.114	48.199
TGT09	634272.208	7402312.584	218.279	0.114	54.540
TGT10	634283.395	7402297.142	218.947	0.110	48.738
TGT10	634283.395	7402297.142	218.947	0.110	48.738
TGT10	634283.410	7402297.144	218.960	0.115	53.056
TGT11	634348.632	7402372.725	218.292	0.113	52.500
TGT11	634348.639	7402372.724	218.295	0.111	51.171
TGT11	634348.639	7402372.724	218.295	0.111	51.171
TGT11	634348.676	7402372.715	218.276	0.111	150.989
TGT12	634360.476	7402357.561	218.943	0.108	51.863
TGT12	634360.479	7402357.537	218.932	0.141	150.126
TGT12	634360.489	7402357.566	218.943	0.117	50.971
TGT12	634360.489	7402357.566	218.943	0.117	50.971
TGT13	634428.994	7402435.914	218.236	0.113	48.268
TGT13	634429.002	7402435.941	218.268	0.128	152.740
TGT13	634429.002	7402435.941	218.268	0.128	152.740
TGT13	634429.010	7402435.922	218.248	0.115	52.365
TGT14	634442.260	7402421.569	218.893	0.113	47.158
TGT14	634442.277	7402421.574	218.898	0.115	53.243
TGT15	634505.233	7402495.884	218.317	0.114	52.972
TGT15	634505.255	7402495.893	218.329	0.109	50.373
TGT16	634518.520	7402481.103	219.006	0.147	150.351

TGT16	634518.532	7402481.101	219.003	0.112	50.864
TGT16	634518.558	7402481.117	219.011	0.113	52.133
TGT17	634599.181	7402544.280	218.949	0.114	48.692
TGT17	634599.187	7402544.241	218.925	0.143	145.885
TGT17	634599.192	7402544.275	218.940	0.112	52.851
TGT18	634585.796	7402559.312	218.326	0.111	49.754
TGT18	634585.807	7402559.310	218.315	0.115	52.433
TGT19	634662.469	7402619.592	218.419	0.113	50.803
TGT19	634662.482	7402619.614	218.445	0.114	49.771
TGT19	634662.503	7402619.609	218.430	0.125	149.050
TGT20	634675.551	7402603.718	219.131	0.111	49.624
TGT20	634675.555	7402603.738	219.140	0.113	50.464
TGT21	634755.435	7402666.430	219.102	0.114	53.428
TGT22	634740.868	7402681.422	218.470	0.114	51.990

6.2 *Appendix 1' 30" Scanned Targets*

100.1.30 - Scanned Targets					
Target Name	Easting	Northing	RL	Target Size	Target Distance
TGT01	633955.469	7402063.488	217.824	0.128	49.801
TGT01	633955.444	7402063.504	217.864	0.134	51.918
TGT02	633967.623	7402050.852	218.921	0.121	51.618
TGT02	633967.600	7402050.871	218.931	0.125	49.999
TGT03	634033.902	7402125.093	218.035	0.129	49.827
TGT03	634033.857	7402125.111	217.989	0.123	53.276
TGT03	634033.819	7402125.135	217.762	0.174	151.256
TGT04	634046.095	7402111.680	219.033	0.118	52.010
TGT05	634112.259	7402186.649	218.123	0.130	48.285
TGT05	634112.216	7402186.700	218.052	0.087	52.196
TGT06	634124.339	7402172.556	218.900	0.125	49.221
TGT07	634191.121	7402248.792	218.126	0.130	52.705
TGT07	634191.172	7402248.755	218.161	0.143	50.178
TGT08	634203.758	7402235.045	219.015	0.130	51.644
TGT09	634272.222	7402312.542	218.153	0.133	49.596
TGT09	634272.252	7402312.535	218.195	0.132	52.067
TGT09	634272.196	7402312.554	218.177	0.156	149.502
TGT11	634348.675	7402372.679	218.263	0.117	50.017
TGT12	634360.501	7402357.534	219.004	0.117	53.168
TGT13	634429.030	7402435.893	218.169	0.116	51.212
TGT14	634442.293	7402421.545	218.977	0.117	53.119
TGT15	634505.229	7402495.886	218.254	0.123	49.642
TGT15	634505.260	7402495.871	218.239	0.140	52.892
TGT16	634518.549	7402481.132	219.107	0.135	50.963
TGT16	634518.553	7402481.089	219.067	0.128	51.874
TGT17	634585.813	7402559.301	218.201	0.137	52.261
TGT18	634599.196	7402544.272	219.017	0.127	50.666
TGT19	634662.510	7402619.584	218.323	0.124	48.009
TGT19	634662.482	7402619.579	218.313	0.128	52.530
TGT20	634675.580	7402603.711	219.198	0.124	48.141
TGT21	634740.902	7402681.379	218.372	0.125	49.678

6.3 *Appendix 3'00" Scanned Targets*

100.3.00 - Scanned Targets					
Target Name	Easting	Northing	RL	Target Size	Target Distance
TGT01	633955.436	7402063.490	217.903	0.125	51.928
TGT01	633955.457	7402063.456	217.948	0.123	49.800
TGT02	633967.601	7402050.862	218.906	0.119	50.007
TGT02	633967.619	7402050.821	218.987	0.131	51.620
TGT03	634033.863	7402125.095	217.974	0.074	53.279
TGT03	634033.867	7402125.116	218.076	0.130	49.817
TGT04	634046.107	7402111.688	219.036	0.123	51.054
TGT04	634046.110	7402111.667	218.963	0.118	52.015
TGT05	634112.216	7402186.670	218.098	0.118	52.205
TGT05	634112.230	7402186.680	218.208	0.121	48.281
TGT06	634124.313	7402172.582	218.864	0.129	51.466
TGT06	634124.320	7402172.589	218.944	0.124	49.216
TGT07	634191.108	7402248.778	218.119	0.136	52.585
TGT07	634191.134	7402248.777	218.199	0.128	50.166
TGT08	634203.756	7402235.037	218.989	0.131	51.514
TGT08	634203.783	7402235.041	219.041	0.122	51.632
TGT09	634272.200	7402312.565	218.191	0.130	49.602
TGT09	634272.214	7402312.549	218.271	0.133	52.198
TGT10	634283.398	7402297.126	218.949	0.120	50.102
TGT10	634283.407	7402297.104	219.054	0.132	51.914
TGT11	634348.653	7402372.690	218.222	0.120	52.786
TGT11	634348.680	7402372.669	218.266	0.129	50.013
TGT12	634360.500	7402357.533	218.969	0.126	53.172
TGT12	634360.519	7402357.506	219.027	0.116	49.767
TGT13	634429.007	7402435.861	218.144	0.138	49.652
TGT13	634429.012	7402435.908	218.202	0.121	51.209
TGT14	634442.280	7402421.564	218.958	0.131	53.117
TGT14	634442.281	7402421.524	218.888	0.116	48.078
TGT15	634505.240	7402495.874	218.325	0.135	49.634
TGT15	634505.266	7402495.854	218.286	0.162	52.879
TGT16	634518.555	7402481.105	219.118	0.142	50.956
TGT16	634518.568	7402481.076	219.063	0.141	51.865
TGT17	634585.806	7402559.309	218.260	0.133	52.261
TGT17	634585.815	7402559.305	218.266	0.142	51.569
TGT18	634599.184	7402544.282	218.983	0.129	50.666
TGT19	634662.490	7402619.555	218.311	0.126	52.534
TGT20	634675.579	7402603.693	219.102	0.120	52.079
TGT20	634675.581	7402603.705	219.185	0.131	48.144
TGT21	634740.861	7402681.416	218.457	0.121	49.673
TGT22	634755.432	7402666.430	219.191	0.121	51.809

6.4 *Appendix 4'30" Scanned Targets*

100.4.30 - Scanned Targets					
Target Name	Easting	Northing	RL	Target Size	Target Distance
TGT01	633955.400	7402063.534	217.978	0.127	51.932
TGT01	633955.451	7402063.477	218.008	0.123	49.802
TGT02	633967.563	7402050.894	218.846	0.127	50.013
TGT02	633967.615	7402050.834	218.911	0.122	51.621
TGT03	634033.827	7402125.136	218.047	0.121	53.286
TGT03	634033.857	7402125.127	218.160	0.128	49.812
TGT04	634046.071	7402111.700	218.891	0.127	52.020
TGT04	634046.096	7402111.688	218.976	0.128	51.048
TGT05	634112.183	7402186.712	218.193	0.126	52.208
TGT06	634124.277	7402172.616	218.794	0.131	51.469
TGT06	634124.306	7402172.592	218.856	0.125	49.211
TGT07	634191.103	7402248.783	218.166	0.132	52.584
TGT07	634191.122	7402248.788	218.267	0.126	50.162
TGT08	634203.761	7402235.041	218.884	0.119	51.515
TGT08	634203.771	7402235.043	218.958	0.126	51.628
TGT09	634272.172	7402312.596	218.281	0.126	49.559
TGT09	634272.172	7402312.598	218.350	0.126	52.200
TGT10	634283.375	7402297.152	218.881	0.120	50.072
TGT10	634283.383	7402297.156	218.976	0.127	51.921
TGT11	634348.626	7402372.705	218.267	0.131	52.770
TGT12	634360.476	7402357.543	218.855	0.124	53.163
TGT12	634360.488	7402357.537	218.953	0.120	49.799
TGT13	634428.975	7402435.928	218.245	0.139	49.738
TGT13	634428.989	7402435.918	218.301	0.132	51.214
TGT13	634429.047	7402435.888	218.348	0.169	151.514
TGT14	634442.242	7402421.581	218.849	0.138	48.163
TGT14	634442.257	7402421.570	218.916	0.119	53.127
TGT15	634505.259	7402495.855	218.317	0.120	52.883
TGT15	634505.263	7402495.879	218.369	0.136	49.529
TGT16	634518.565	7402481.097	219.024	0.145	50.852
TGT16	634518.570	7402481.082	218.927	0.125	51.868
TGT17	634585.773	7402559.347	218.393	0.117	51.562
TGT17	634585.783	7402559.331	218.317	0.133	52.267
TGT18	634599.170	7402544.301	218.861	0.125	50.669
TGT18	634599.175	7402544.327	218.966	0.120	53.078
TGT19	634662.465	7402619.577	218.412	0.128	52.538
TGT19	634662.487	7402619.612	218.511	0.132	48.012
TGT20	634675.556	7402603.727	219.148	0.131	48.135
TGT20	634675.560	7402603.715	219.027	0.127	52.080
TGT21	634740.834	7402681.440	218.546	0.118	49.668
TGT22	634755.410	7402666.451	219.093	0.119	51.805

6.5 *Appendix 6'00" Scanned Targets*

100.6.00 - Scanned Targets					
Target Name	Easting	Northing	RL	Target Size	Target Distance
TGT01	633955.434	7402063.505	217.924	0.126	51.467
TGT01	633955.474	7402063.486	217.994	0.125	49.807
TGT02	633967.602	7402050.864	218.878	0.117	49.556
TGT02	633967.639	7402050.842	218.928	0.126	51.628
TGT03	634033.836	7402125.113	218.042	0.100	53.289
TGT03	634033.871	7402125.122	218.131	0.123	50.251
TGT03	634033.927	7402125.096	218.165	0.140	148.969
TGT04	634046.081	7402111.681	218.910	0.131	52.026
TGT04	634046.104	7402111.688	218.974	0.122	51.492
TGT04	634046.183	7402111.636	219.023	0.163	150.371
TGT05	634112.191	7402186.691	218.168	0.129	52.212
TGT05	634112.211	7402186.688	218.260	0.121	48.270
TGT06	634124.289	7402172.599	218.815	0.126	51.472
TGT06	634124.302	7402172.594	218.883	0.130	49.206
TGT07	634191.115	7402248.780	218.113	0.139	52.579
TGT07	634191.116	7402248.787	218.256	0.135	50.158
TGT08	634203.766	7402235.047	218.987	0.128	51.623
TGT08	634203.771	7402235.041	218.891	0.131	51.508
TGT09	634272.173	7402312.589	218.246	0.128	49.564
TGT09	634272.187	7402312.591	218.349	0.136	52.205
TGT10	634283.375	7402297.144	218.886	0.127	50.077
TGT10	634283.393	7402297.150	219.023	0.127	51.924
TGT11	634348.625	7402372.694	218.261	0.123	52.777
TGT11	634348.646	7402372.700	218.339	0.129	50.031
TGT12	634360.478	7402357.533	218.898	0.107	53.167
TGT12	634360.486	7402357.533	218.986	0.128	49.793
TGT13	634428.985	7402435.916	218.301	0.125	51.209
TGT13	634428.997	7402435.884	218.221	0.144	49.740
TGT14	634442.257	7402421.567	218.939	0.120	53.124
TGT14	634442.276	7402421.548	218.847	0.133	48.166
TGT15	634505.226	7402495.903	218.382	0.135	49.522
TGT15	634505.239	7402495.883	218.328	0.131	52.886
TGT16	634518.539	7402481.103	218.955	0.119	51.870
TGT16	634518.543	7402481.134	219.051	0.138	50.847
TGT17	634585.793	7402559.303	218.323	0.124	52.270
TGT17	634585.799	7402559.315	218.383	0.122	51.557
TGT18	634599.186	7402544.278	218.890	0.129	50.674
TGT18	634599.193	7402544.286	218.976	0.118	53.075
TGT19	634662.454	7402619.600	218.411	0.134	52.508
TGT19	634662.467	7402619.618	218.495	0.125	48.005
TGT20	634675.543	7402603.732	219.040	0.123	52.061
TGT20	634675.546	7402603.742	219.158	0.127	48.132

6.6 *Appendix 7'30" Scanned Targets*

100.7.30 - Scanned Targets					
Target Name	Easting	Northing	RL	Target Size	Target Distance
TGT01	633955.426	7402063.506	217.924	0.122	51.473
TGT01	633955.466	7402063.508	218.025	0.122	49.816
TGT02	633967.596	7402050.861	218.865	0.123	49.563
TGT02	633967.632	7402050.865	218.933	0.128	51.632
TGT03	634033.838	7402125.101	218.044	0.132	53.293
TGT03	634033.858	7402125.126	218.170	0.128	50.243
TGT04	634046.087	7402111.669	218.885	0.129	52.033
TGT04	634046.098	7402111.693	218.977	0.127	51.488
TGT05	634112.182	7402186.695	218.201	0.135	52.216
TGT05	634112.191	7402186.702	218.294	0.126	48.265
TGT05	634112.233	7402186.712	218.414	0.172	149.255
TGT06	634124.282	7402172.602	218.801	0.129	51.476
TGT06	634124.287	7402172.610	218.889	0.120	49.199
TGT06	634124.318	7402172.630	218.998	0.147	150.068
TGT07	634191.106	7402248.792	218.269	0.126	50.154
TGT07	634191.107	7402248.799	218.129	0.134	52.575
TGT08	634203.759	7402235.049	218.967	0.124	51.619
TGT08	634203.764	7402235.055	218.866	0.129	51.504
TGT09	634272.175	7402312.571	218.273	0.128	49.569
TGT09	634272.193	7402312.594	218.362	0.129	52.210
TGT10	634283.382	7402297.132	218.882	0.119	50.082
TGT10	634283.396	7402297.148	218.986	0.129	51.929
TGT11	634348.623	7402372.715	218.349	0.124	50.027
TGT11	634348.629	7402372.679	218.288	0.123	52.778
TGT12	634360.469	7402357.552	218.969	0.120	49.788
TGT12	634360.487	7402357.525	218.888	0.120	53.168
TGT13	634428.968	7402435.928	218.311	0.141	51.206
TGT13	634428.984	7402435.898	218.239	0.140	49.744
TGT13	634428.988	7402435.938	218.400	0.143	151.502
TGT14	634442.241	7402421.586	218.917	0.126	53.119
TGT14	634442.260	7402421.558	218.853	0.131	48.168
TGT15	634505.234	7402495.895	218.387	0.154	49.521
TGT15	634505.242	7402495.872	218.334	0.127	52.889
TGT16	634518.543	7402481.120	219.027	0.129	50.843
TGT16	634518.545	7402481.094	218.968	0.118	51.872
TGT17	634599.173	7402544.286	218.913	0.125	50.675
TGT17	634599.182	7402544.291	218.967	0.118	53.068
TGT18	634585.784	7402559.317	218.325	0.135	52.272
TGT18	634585.790	7402559.318	218.380	0.124	51.553
TGT19	634662.465	7402619.572	218.392	0.141	52.513
TGT19	634662.479	7402619.606	218.498	0.120	48.003
TGT20	634675.551	7402603.724	219.164	0.119	48.128

TGT20	634675.557	7402603.710	219.066	0.131	52.067
TGT21	634755.405	7402666.454	219.177	0.132	51.834
TGT22	634740.828	7402681.441	218.570	0.123	49.685

6.7 *Appendix Base Surface Residuals*

Base Surface - Residuals			
Target Name	Easting	Northing	RL
TGT01	0.024	0.009	0.002
TGT01	0.018	-0.004	0.001
TGT02	0.019	0.014	0.001
TGT02	0.011	-0.003	-0.025
TGT03	0.016	0.011	0.011
TGT03	-0.005	0.007	-0.003
TGT03	-0.017	0.008	0.026
TGT04	0.015	0.012	-0.022
TGT04	-0.006	0.003	-0.001
TGT04	-0.018	0.009	-0.001
TGT05	-0.009	-0.008	0.027
TGT06	-0.007	0.009	0.004
TGT07	0.010	0.005	0.011
TGT07	-0.033	-0.033	0.001
TGT08	0.019	0.005	-0.002
TGT08	-0.026	-0.006	0.013
TGT09	0.032	-0.008	0.004
TGT09	0.008	0.013	0.011
TGT09	0.008	0.013	0.011
TGT09	-0.011	0.008	0.016
TGT10	0.009	0.011	-0.005
TGT10	0.009	0.011	-0.005
TGT10	-0.006	0.009	-0.018
TGT11	0.008	-0.010	0.006
TGT11	0.001	-0.009	0.003
TGT11	0.001	-0.009	0.003
TGT11	-0.036	0.000	0.022
TGT12	0.001	0.004	-0.007
TGT12	-0.002	0.028	0.004
TGT12	-0.012	-0.001	-0.007
TGT12	-0.012	-0.001	-0.007
TGT13	0.004	0.009	0.024
TGT13	-0.004	-0.018	-0.008
TGT13	-0.004	-0.018	-0.008
TGT13	-0.012	0.001	0.012
TGT14	-0.004	0.003	-0.001

TGT14	-0.021	-0.002	-0.006
TGT15	0.020	-0.001	0.014
TGT15	-0.002	-0.010	0.002
TGT16	0.021	0.005	-0.024
TGT16	0.009	0.007	-0.021
TGT16	-0.017	-0.009	-0.029
TGT17	0.001	0.002	-0.010
TGT17	-0.005	0.041	0.014
TGT17	-0.010	0.007	-0.001
TGT18	-0.003	0.005	0.013
TGT18	-0.014	0.007	0.024
TGT19	0.008	0.022	0.032
TGT19	-0.005	0.000	0.006
TGT19	-0.026	0.005	0.021
TGT20	-0.010	0.009	0.003
TGT20	-0.014	-0.011	-0.006
TGT21	-0.010	-0.023	-0.020
TGT22	-0.011	-0.017	-0.001

6.8 *Appendix Base Surface Height Residuals*

Surveyed (GPS)		Base Run	
Point Id	**RL**	**Model**	**Residual**
1	218.038	218.052	-0.014
2	218.080	218.082	-0.002
3	218.106	218.124	-0.018
4	218.190	218.199	-0.009
5	218.206	218.219	-0.013
6	218.215	218.241	-0.026
7	218.248	218.272	-0.024
8	218.224	218.249	-0.025
9	218.268	218.271	-0.003
10	218.262	218.275	-0.013
11	218.261	218.266	-0.005
12	218.263	218.275	-0.012
13	218.281	218.277	0.004
14	218.271	218.253	0.018
15	218.310	218.302	0.008
16	218.278	218.272	0.006
17	218.280	218.303	-0.023
18	218.278	218.288	-0.010
19	218.321	218.332	-0.011
20	218.349	218.383	-0.034

6.9 *Appendix Scan Surface Duration Height Residuals*

Surveyed (GPS)		1.1.30		1.3.00		1.4.30		1.6.00		1.7.30	
Point Id	RL	Model	Residual	Model	Residual	Model	Residual	Model	Residual	Model	Residual
1	218.038	218.032	0.006	218.036	0.002	218.082	-0.044	218.029	0.009	218.036	0.002
2	218.080	218.076	0.004	218.089	-0.009	218.091	-0.011	218.080	0.000	218.086	-0.006
3	218.106	218.124	-0.018	218.131	-0.025	218.102	0.004	218.139	-0.033	218.144	-0.038
4	218.190	218.189	0.001	218.190	0.000	218.186	0.004	218.203	-0.013	218.209	-0.019
5	218.206	218.210	-0.004	218.216	-0.010	218.217	-0.011	218.234	-0.028	218.222	-0.016
6	218.215	218.222	-0.007	218.245	-0.030	218.236	-0.021	218.249	-0.034	218.247	-0.032
7	218.248	218.278	-0.030	218.295	-0.047	218.258	-0.010	218.265	-0.017	218.247	0.001
8	218.224	218.237	-0.013	218.254	-0.030	218.242	-0.018	218.239	-0.015	218.227	-0.003
9	218.268	218.262	0.006	218.252	0.016	218.260	0.008	218.276	-0.008	218.261	0.007
10	218.262	218.247	0.015	218.259	0.003	218.249	0.013	218.260	0.002	218.273	-0.011
11	218.261	218.268	-0.007	218.314	-0.053	218.262	-0.001	218.285	-0.024	218.284	-0.023
12	218.263	218.262	0.001	218.265	-0.002	218.259	0.004	218.273	-0.010	218.277	-0.014
13	218.281	218.271	0.010	218.289	-0.008	218.266	0.015	218.295	-0.014	218.305	-0.024
14	218.271	218.233	0.038	218.256	0.015	218.247	0.024	218.258	0.013	218.272	-0.001
15	218.310	218.310	0.000	218.309	0.001	218.297	0.013	218.336	-0.026	218.315	-0.005
16	218.278	218.278	0.000	218.275	0.003	218.272	0.006	218.279	-0.001	218.284	-0.006
17	218.280	218.286	-0.006	218.296	-0.016	218.296	-0.016	218.294	-0.014	218.293	-0.013
18	218.278	218.263	0.015	218.272	0.006	218.294	-0.016	218.299	-0.021	218.300	-0.022
19	218.321	218.301	0.020	218.327	-0.006	218.359	-0.038	218.331	-0.010	218.360	-0.039
20	218.349	218.358	-0.009	218.369	-0.020	218.343	0.006	218.358	-0.009	218.399	-0.050

6.10 *Appendix 1'30" Residuals*

100.1.30 - Residuals			
Target Name	Easting	Northing	RL
TGT01	-0.017	0.019	0.159
TGT01	0.008	0.003	0.119
TGT02	-0.011	0.019	-0.020
TGT02	0.012	0.000	-0.030
TGT03	-0.040	0.038	0.061
TGT03	0.005	0.020	0.107
TGT03	0.043	-0.004	0.334
TGT04	0.007	0.019	-0.107
TGT05	-0.054	0.050	0.096
TGT05	-0.011	-0.001	0.167
TGT06	-0.036	0.066	-0.073
TGT07	0.005	0.006	0.069
TGT07	-0.046	0.043	0.034
TGT08	0.027	0.007	-0.093
TGT09	-0.025	0.050	0.142
TGT09	-0.055	0.057	0.100
TGT09	0.001	0.038	0.118
TGT11	-0.035	0.036	0.035
TGT12	-0.024	0.031	-0.068
TGT13	-0.032	0.030	0.091
TGT14	-0.037	0.027	-0.085
TGT15	0.024	-0.003	0.077
TGT15	-0.007	0.012	0.092
TGT16	-0.008	-0.024	-0.125
TGT16	-0.012	0.019	-0.085
TGT17	-0.020	0.016	0.138
TGT18	-0.014	0.010	-0.078
TGT19	-0.033	0.030	0.128
TGT19	-0.005	0.035	0.138
TGT20	-0.039	0.016	-0.064
TGT21	-0.045	0.026	0.097

6.11 *Appendix 3'00" Residuals*

100.3.00 - Residuals			
Target Name	Easting	Northing	RL
TGT01	0.016	0.017	0.080
TGT01	-0.005	0.051	0.035
TGT02	0.011	0.009	-0.005
TGT02	-0.007	0.050	-0.086
TGT03	-0.001	0.036	0.122
TGT03	-0.005	0.015	0.020
TGT04	-0.005	0.011	-0.110
TGT04	-0.008	0.032	-0.037
TGT05	-0.011	0.029	0.121
TGT05	-0.025	0.019	0.011
TGT06	-0.010	0.040	-0.037
TGT06	-0.017	0.033	-0.117
TGT07	0.018	0.020	0.076
TGT07	-0.008	0.021	-0.004
TGT08	0.029	0.015	-0.067
TGT08	0.002	0.011	-0.119
TGT09	-0.003	0.027	0.104
TGT09	-0.017	0.043	0.024
TGT10	0.006	0.027	-0.007
TGT10	-0.003	0.049	-0.112
TGT11	-0.013	0.025	0.076
TGT11	-0.040	0.046	0.032
TGT12	-0.023	0.032	-0.033
TGT12	-0.042	0.059	-0.091
TGT13	-0.009	0.062	0.116
TGT13	-0.014	0.015	0.058
TGT14	-0.024	0.008	-0.066
TGT14	-0.025	0.048	0.004
TGT15	0.013	0.009	0.006
TGT15	-0.013	0.029	0.045
TGT16	-0.014	0.003	-0.136
TGT16	-0.027	0.032	-0.081
TGT17	-0.013	0.008	0.079
TGT17	-0.022	0.012	0.073
TGT18	-0.002	0.000	-0.044
TGT19	-0.013	0.059	0.140
TGT20	-0.038	0.034	0.032
TGT20	-0.040	0.022	-0.051
TGT21	-0.004	-0.011	0.012
TGT22	-0.007	-0.023	-0.109

6.12 *Appendix 4'30" Residuals*

100.4.30 - Residuals			
Target Name	Easting	Northing	RL
TGT01	0.052	-0.027	0.005
TGT01	0.001	0.030	-0.025
TGT02	0.049	-0.023	0.055
TGT02	-0.003	0.037	-0.010
TGT03	0.035	-0.005	0.049
TGT03	0.005	0.004	-0.064
TGT04	0.031	-0.001	0.035
TGT04	0.006	0.011	-0.050
TGT05	0.022	-0.013	0.026
TGT05	-0.011	0.008	-0.062
TGT06	0.026	0.006	0.033
TGT06	-0.003	0.030	-0.029
TGT07	0.023	0.015	0.029
TGT07	0.004	0.010	-0.072
TGT08	0.024	0.011	0.038
TGT08	0.014	0.009	-0.036
TGT09	0.025	-0.004	0.014
TGT09	0.025	-0.006	-0.055
TGT10	0.029	0.001	0.061
TGT10	0.021	-0.003	-0.034
TGT11	0.014	0.010	0.031
TGT11	-0.006	0.011	-0.024
TGT12	0.001	0.022	0.081
TGT12	-0.011	0.028	-0.017
TGT13	0.023	-0.005	0.015
TGT13	0.009	0.005	-0.041
TGT13	-0.049	0.035	-0.088
TGT14	0.014	-0.009	0.043
TGT14	-0.001	0.002	-0.024
TGT15	-0.006	0.028	0.014
TGT15	-0.010	0.004	-0.038
TGT16	-0.024	0.011	-0.042
TGT16	-0.029	0.026	0.055
TGT17	0.020	-0.030	-0.054
TGT18	0.012	-0.019	0.078
TGT18	0.007	-0.045	-0.027
TGT19	0.012	0.037	0.039
TGT19	-0.010	0.002	-0.060
TGT20	-0.015	0.000	-0.014
TGT20	-0.019	0.012	0.107
TGT21	0.023	-0.035	-0.077

6.13 *Appendix 6'00" Residuals*

100.6.00 - Residuals			
Target Name	Easting	Northing	RL
TGT01	0.018	0.002	0.059
TGT01	-0.022	0.021	-0.011
TGT02	0.010	0.007	0.023
TGT02	-0.027	0.029	-0.027
TGT03	0.026	0.018	0.054
TGT03	-0.009	0.009	-0.035
TGT03	-0.065	0.035	-0.069
TGT04	0.021	0.018	0.016
TGT04	-0.002	0.011	-0.048
TGT04	-0.081	0.063	-0.097
TGT05	0.014	0.008	0.051
TGT05	-0.006	0.011	-0.041
TGT06	0.014	0.023	0.012
TGT06	0.001	0.028	-0.056
TGT07	0.011	0.018	0.082
TGT07	0.010	0.011	-0.061
TGT08	0.019	0.005	-0.065
TGT08	0.014	0.011	0.031
TGT09	0.024	0.003	0.049
TGT09	0.010	0.001	-0.054
TGT10	0.029	0.009	0.056
TGT10	0.011	0.003	-0.081
TGT11	0.015	0.021	0.037
TGT11	-0.006	0.015	-0.041
TGT12	-0.001	0.032	0.038
TGT12	-0.009	0.032	-0.050
TGT13	0.013	0.007	-0.041
TGT14	-0.001	0.005	-0.047
TGT14	-0.020	0.024	0.045
TGT15	0.027	-0.020	-0.051
TGT15	0.014	0.000	0.003
TGT16	0.002	0.005	0.027
TGT16	-0.002	-0.026	-0.069
TGT17	0.000	0.014	0.016
TGT17	-0.006	0.002	-0.044
TGT18	-0.004	0.004	0.049
TGT18	-0.011	-0.004	-0.037
TGT19	0.023	0.014	0.040
TGT19	0.010	-0.004	-0.044
TGT20	-0.002	-0.005	0.094
TGT20	-0.005	-0.015	-0.024
TGT22	0.011	-0.033	-0.076

6.14 *Appendix 7'30" Residuals*

100.7.30 - Residuals			
Target Name	Easting	Northing	RL
TGT01	0.026	0.001	0.059
TGT01	-0.014	-0.001	-0.042
TGT02	0.016	0.010	0.036
TGT02	-0.020	0.006	-0.032
TGT03	0.024	0.030	0.052
TGT03	0.004	0.005	-0.074
TGT04	0.015	0.030	0.041
TGT04	0.004	0.006	-0.051
TGT05	0.023	0.004	0.018
TGT05	0.014	-0.003	-0.075
TGT05	-0.028	-0.013	-0.195
TGT06	0.021	0.020	0.026
TGT06	0.016	0.012	-0.062
TGT06	-0.015	-0.008	-0.171
TGT07	0.020	0.006	-0.074
TGT07	0.019	-0.001	0.066
TGT08	0.021	-0.003	0.056
TGT09	0.022	0.021	0.022
TGT09	0.004	-0.002	-0.067
TGT10	0.008	0.005	-0.044
TGT11	0.017	0.000	-0.051
TGT11	0.011	0.036	0.010
TGT12	-0.010	0.040	0.048
TGT13	0.030	-0.005	-0.051
TGT13	0.014	0.025	0.021
TGT13	0.010	-0.015	-0.140
TGT14	0.015	-0.014	-0.025
TGT14	-0.004	0.014	0.039
TGT15	0.019	-0.012	-0.056
TGT15	0.011	0.011	-0.003
TGT16	-0.004	0.014	0.014
TGT17	0.009	-0.004	0.026
TGT17	0.000	-0.009	-0.028
TGT18	0.009	0.000	0.014
TGT18	0.003	-0.001	-0.041
TGT19	0.012	0.042	0.059
TGT19	-0.002	0.008	-0.047
TGT20	-0.010	0.003	-0.030
TGT21	0.020	-0.047	-0.095
TGT22	0.029	-0.036	-0.101

6.15 *Appendix Project Specifications*

University of Southern Queensland

FACULTY OF ENGINEERING AND SURVEYING

ENG 4111/4112 Research Project

PROJECT SPECIFICATION

FOR: **Simon Matthew JONES**

TOPIC: INVESTIGATE THE OPTIMUM PARAMETERS ASSOCIATED WITH STOP-GO MOBILE MAPPING

SUPERVISORS: Dr Peter Gibbings

Tim Baillie, T.R. Baillie Consulting Surveyors

SPONSORSHIP: T.R. Baillie Consulting Surveyors

PROJECT AIM: To investigate and test for the optimum scan resolutions, positions, adjustment parameters and ultimately the accuracies of stop-go mobile mapping using a Terrestrial Laser Scanner, which incorporates a multi-station adjustment.

PROGRAMME: Issue A, 23rd March 2010

6. Scan an entire open cut pit several times (the pit must be large enough that numerous scans are required to cover the whole area). Each scan sequence should follow the procedures below:
    a. Series A -minimum distances between scans
       - alter scan resolutions
    b. Series B -average distances between scans
       - alter scan resolutions
    c. Series C -maximum distances between scans
       - alter scan resolutions
7. Perform a multi-station adjustment on the data, using a range of parameters. These parameters should be consistent for the three scan series.
8. Create a Digital Terrain Model for each of the adjusted scan sequences.
9. Test the accuracy of each model by:
    a. Cut/fill comparison between an extremely accurate survey (scan positions very close and of high resolution or pickups from a total station)
    b. Physically stake out points from the DTM's that are created and compare them to the field
10. Compare and contrast these results and find the optimum scan resolutions, positions and adjustment parameters.

AGREED:

(Student) (Supervisor)

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